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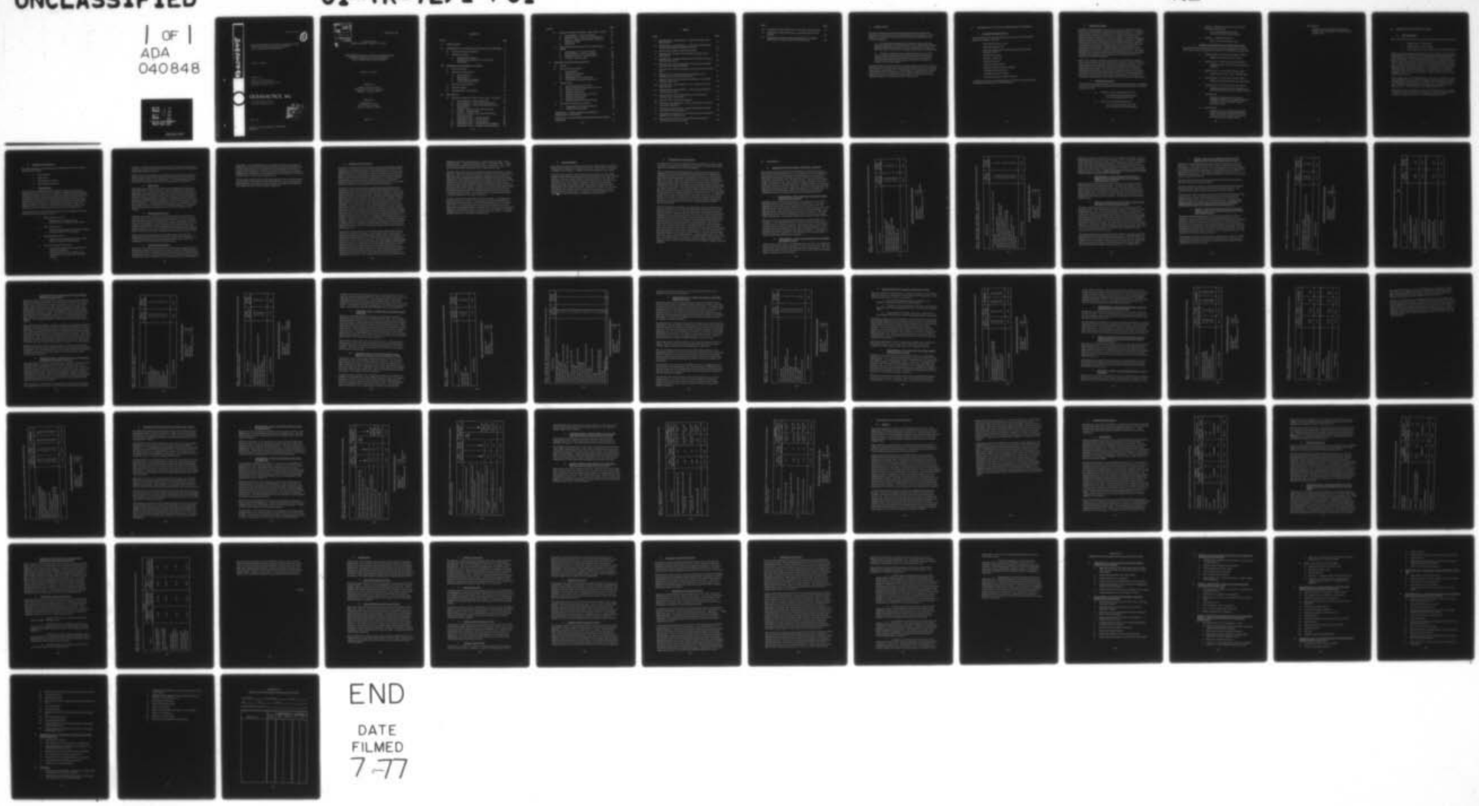

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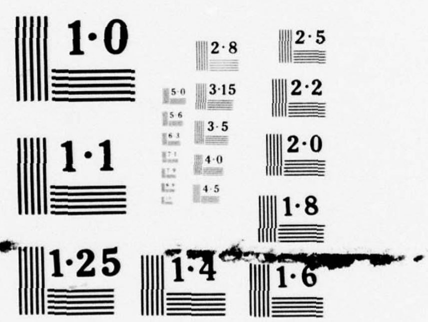

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DIVER PERFORMANCE AND HUMAN ENGINEERING TESTS SALVAGE EQUIPMENT EVALUATION PROGRAM U.S.N./MAKAI RANGE AEGIR HABITAT

Birger G. Andersen

Prepared for:

Office of Naval Research
Engineering Psychology Programs
Arlington, Virginia 22217

OCEANAUTICS, Inc.

5520 Caminito Consuelo
La Jolla, California 92037

May 1972

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Technical Report
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CONTENTS

Section				Page
I.	INTRODUCTION			1
II.	DESCRIPTION OF THE OCEAN FLOOR SALVAGE TOOL PROGRAM			2
	A.	Tools and Salvage Equipment		2
	B.	Salvage Tool Tasks		3
		1.	Individual Tool Tasks	3
		2.	Multiple Tool Applications on Simulated Work Tasks	4
III.	PERFORMANCE MEASUREMENT PROGRAM			6
	A.	Test Environment		6
	B.	Measures of Performance		7
		1.	Time Measures	7
		2.	Work Output	8
		3.	Physiological Measures	8
		4.	Diver Debriefing Reports	8
	C.	Measurement Techniques		10
	D.	Personal Apparel		12
	E.	Test Equipment and Apparatus		13
IV.	TEST RESULTS			14
	A.	Training and Baseline Program, Point Mugu, California		14
		1.	Load Handling -- Move Test Stand	14
		2.	Load Handling -- Move Tool Box/Manifold	14
		3.	Load Handling -- Return Test Stand and Tool/ Box Manifold	17
		4.	Cutting -- Hydraulic Open-Center Cutter	17
		5.	Cutting -- Abrasive Saw	18
		6.	Cutting -- Enerpac Diver-Powered Hydraulic Pump and Cutters	18
		7.	Combination Task -- Install Eyebolt	21
		8.	Combination Task -- Install Eyenut	21
		9.	Combination Task -- Install Eyenut	24
		10.	Combination Task -- Install Three-Bolt Padeye	24
		11.	Combination Task -- Install Three-Bolt Padeye	27

Section			Page
	B.	Training and Baseline Program, Makai Range, Hawaii	29
		1. Load Handling -- Move Test Stand	29
		2. Load Handling -- Move Tool Box/Manifold	31
		3. Cutting -- Enerpac Diver-Powered Hydraulic Pump and Cutters	31
		4. Drill Press	31
	C.	Two-Hundred-Foot Saturation Dive, Makai Range, Hawaii	36
		1. Load Handling -- Move Test Stand	37
		2. Load Handling -- Return Test Stand	37
		3. Combination Task -- Install Eyebolt	40
		4. Cutting -- Abrasive Saw	40
V.	DISCUSSION AND RECOMMENDATIONS		43
	A.	General	43
	B.	Salvage Task Performance	45
		1. Load Handling	45
		2. Abrasive Saw Cutting	47
		3. Combination Task	47
		4. Performance Time Comparisons	49
		5. Conclusions and Recommendations	49
	C.	Salvage Tools	52
		1. Open-Center Hydraulic Cutter	52
		2. Enerpac Hydraulic Hand Pump and Cutter	52
		3. Hydraulic Impact Tool	53
		4. Velocity Power Tool	53
		5. Hydraulic Power Handle and Winch	53
		6. Hydraulic Abrasive Saw	53
		7. Hydraulic Drill Press	54
		8. Aqualift Variable Buoyancy Pontoons	54
	D.	Performance Measurement System	55
		1. Organization and Program Planning	55
		2. Performance Observation	56
	ADDENDUM A. DETAILED ACTIVITY ANALYSIS OF SCHEDULED SALVAGE TASKS		59
	ADDENDUM B. SALVAGE TASK PERFORMANCE MEASUREMENT DATA FORM		65

TABLES

Table		Page
1.	Summary Data, Load Handling -- Move Test Stand Using Large Aqualift	15
2.	Summary Data, Load Handling -- Move Tool Box/Manifold Using Large Aqualift and Hydraulic Winch	16
3.	Summary Data, Abrasive Saw Cutting Task	19
4.	Summary Data, Enerpac Diver-Operated Hydraulic Pump and Cutters	20
5.	Summary Data, Eyebolt Installation Using Hydraulic Impact Tool to Drill and Tap	22
6.	Summary Data, Eyenut Installation Using Hydraulic Impact Tool with Combination Drill/Tap	23
7.	Summary Data, Eyenut Installation Using MSA Velocity Power Tool	25
8.	Summary Data, Three-Bolt Padeye Installation Using Hydraulic Impact Tool to Drill and Tap	26
9.	Summary Data, Three-Bolt Padeye Installation Using MSA Velocity Power Tool	28
10.	Summary Data, Load Handling -- Move Test Stand Using Large Aqualift	30
11.	Summary Data, Load Handling -- Move Tool Box/Manifold Using Small Aqualift	32
12.	Summary Data, Cutting Using Enerpac Diver-Operated Hydraulic Pump and Cutters	33
13.	Summary Data, Drill Press Operation	35
14.	Test Data, Load Handling -- Move Test Stand to Work Site Using Large Aqualift	38
15.	Test Data, Load Handling -- Return Test Stand from Work Site to AEGIR Using Aqualifts	39
16.	Installation of Eyebolt in 1-inch Mild Steel Using Hydraulic Impact Tool to Drill and Tap	41
17.	Abrasive Saw Cutting 1-1/2-inch-square Steel Bar and 1/2-inch by 6-inch Steel Plate	42

Table		Page
18.	Comparative Task Activity Times, Test Stand Load Handling	46
19.	Comparative Task Activity Times, Hydraulic Abrasive Saw Cutting	48
20.	Comparison of Selected Tasks Performed Both in Shallow Water and at 200 Feet during the Saturation Dive	50

I. INTRODUCTION

The diver performance and human engineering tests were planned and carried out in conjunction with the NCEL salvage tool evaluation. These tests were conducted as part of the overall ocean floor program for the following purposes:

1. To obtain both quantitative and qualitative data of the performance capabilities and limitations of divers to effectively operate selected underwater salvage tools and tool systems in carrying out work tasks which would meet the design specifications of these tools.

2. To collect underwater diver performance data that could be used to further the development of human engineering criteria for the design and fabrication of advanced tools and to contribute to meet more effectively the demanding requirements of the Navy's manned, deep-diving systems.

Overall program plans called for the joint development of tool test scenarios by Oceanautics and NCEL that would meet the requirements of both the performance and engineering tests. Data relating to the performance measurement program would be collected in three phases: baseline and training data at Point Mugu, familiarization data during the 200-foot dive, and a complete salvage test program during the 520-foot dive.

II. DESCRIPTION OF THE OCEAN FLOOR SALVAGE TOOL PROGRAM

A. Tools and Salvage Equipment

The underwater tools and salvage equipment used for the ocean floor salvage tool program included:

- open-center hydraulic cutter
- hydraulic abrasive saw
- diver-operated Enerpac hydraulic pump and associated hydraulic cutters
- hydraulic drill press
- hydraulic impact tool
- velocity power tool
- hydraulic-powered winch
- Aqualift variable buoyancy pontoons
- underwater work test stand
- underwater tool box/manifold
- tool-and-equipment-storage container

A detailed description and specifications for these tools and equipment are presented in Section B2, "Salvage Tools."

B. Salvage Tool Tasks

Saturated diving operations place divers in a unique underwater environment where surface logistic support for tool work is difficult. Divers may be called upon to perform a wide variety of work tasks requiring a broad range of tools adapted to underwater use. Typical underwater tasks include assembly, fastening, cutting, and drilling. The tools selected by NCEL for testing as part of the ocean floor program represent an excellent cross section of tools employed in actual salvage operations. However, to develop one simulated underwater work task that could exercise all of the selected tools would be prohibitive and not representative of an operational work situation. Overall program plans called for the joint development of tool task scenarios by Oceanautics and NCEL. The tasks selected were to meet both performance and engineering test requirements and had to be performable within specified time limits allotted to the ocean floor salvage tool program.

Early in the program, planning sessions were held at NCEL to develop a set of task scenarios that would meet all the specified requirements of the ocean floor program and utilize all the tools selected for testing. Two types of tasks were proposed to carry out the performance and human engineering test program. The first type would be used to evaluate the functional and engineering capabilities of specified individual tool items to perform selected tasks within the limits of their design specifications. The second type of task would represent a simulation of an operational work task or combination of work tasks requiring multiple tool applications.

1. Individual Tool Tasks

The following tasks were selected to evaluate diver performance in operating a tool item and performing specified functional operations within the design limits of the tool:

a. Cutting -- open-center hydraulic cutter

- Cut 5/8-inch steel reinforcing bar.
- Cut 1-inch-diameter wire rope.

b. Cutting -- hydraulic abrasive saw

- Cut 1-1/2-inch-square steel bar.
- Cut 1/2-inch by 6-inch steel plate.

c. Cutting -- hydraulic cutter and diver-operated Enerpac hydraulic pump

- Cut 1-inch-diameter wire rope.
- Cut 5/8-inch steel reinforcing bar.

d. Drilling -- hydraulic drill press

- Drill 1-1/2-inch-diameter hole.

2. Multiple Tool Applications on Simulated Work Tasks

The following work tasks were selected as being representative of those that a diver would be called upon to perform in an operational salvage job:

a. Install eyebolt in 1-inch steel vertical surface

- Hydraulic impact tool; drill and tap.

b. Install eyenut in 1-inch steel vertical surface

- Hydraulic impact tool; drill and combination drill/tap.

c. Install eyenut in 1-inch steel vertical surface

- Velocity power tool; insert a threaded stud.

d. Install padeye in 1-inch steel vertical surface

- Hydraulic impact tool; drill, tap, and torque.

e. Install padeye in 1-inch steel vertical surface

- Velocity power tool; insert a threaded stud and torque padeye bolts with crescent wrench.

f. Load handling

- Transport underwater work test stand (approximate weight 750 pounds) a distance of 30 feet, using an Aqualift variable buoyancy pontoon.

g. Load handling

- Transport tool box/manifold (approximate weight 350 pounds) a distance to 30 feet, using an Aqualift variable buoyancy pontoon and hydraulic-powered winch.

h. Load handling

- Transport tool box/manifold a distance of 30 feet, using the Aqualift variable buoyancy pontoon only.

III. PERFORMANCE MEASUREMENT PROGRAM

A. Test Environment

Three test environments were used for the performance evaluation program:

1. Shallow water at Point Mugu
2. Shallow water at Makai Range
3. Two-hundred-foot test conditions from the AEGIR habitat

Shallow water conditions were employed for diver training in the operation of the salvage tool systems and for obtaining baseline performance data. These tests were conducted at the Naval Missile Center (NMC), Point Mugu, California, in an open-ocean environment at a depth of 40-50 feet, near the pier at Point Mugu. Water temperature ranged between 52° and 62° F. The proximity of this location to the shore created some amount of bottom surge during the testing period. The amount of surge varied with tidal conditions, surface sea state, and wind conditions. Underwater visibility varied between 5 and 20 feet. At no time during the testing period did surge or visibility conditions interfere with the conduct of the underwater tool tasks.

Prior to deployment of the AEGIR habitat, there was an opportunity to conduct additional baseline tests in the shallow waters adjacent to the pier at Makai Range. These tests were carried out at a water depth of 16-20 feet. Visibility was estimated at less than 8 feet, with no significant surge present. Water temperature was approximately 70° F.

The operational tests performed during the 200-foot saturation dive were carried out off the starboard stern of AEGIR at a depth of 198 feet, with visibility in excess of 100 feet. Water temperature was 65° F.

B. Measures of Performance

The prime measures of the working diver's performance have been broken down into four classes:

1. Time measures
2. Work output
3. Physiological measures
4. Diver debriefing reports

1. Time Measures

Time measures of performance were selected as the primary source of quantitative data for this evaluation program. Whereas past performance evaluation programs carried out in a field environment have relied primarily on obtaining overall times required by divers to complete a work task, it was decided for this program to attempt to obtain more detailed and comprehensive time measures. The goal was to break down the overall work tasks into work units that were representative of discrete events that occurred within the total task. If successful, this would enable a more detailed and more complete evaluation of each diver's performance.

The additional time measures which appeared to be meaningful to the performance evaluation program included:

a. Task performance times
   - Overall time to complete a task.
   - Part-task times for discrete task events.

b. Rest and idle times
   - Diver rest periods after work task commenced.
   - Idle time involving no tool output.

c. Work preparation times
   - Time devoted to preparing the task or tool prior to or during the work period.

d. Service and maintenance times
   - Time devoted to servicing or maintaining tools and equipment.
   - Time required to adjust, check out, or maintain personal apparel or life support systems.

In order to specify and allocate task elements or events with this kind of precision, a complete task analysis was required of each of the tool tasks to be performed by the divers.

While each of the time measurement categories did not apply to all of the divers' scheduled work tasks, those that were relevant and predictable were specified as part of the task analysis. The complete task analysis for each of the salvage tool work tasks is presented in Addendum A.

2. Work Output

Work output was measured with respect to the magnitude or quantity of work achievement during each task. Under most performance evaluation conditions, such measures rely heavily on the ability of the observers to physically inspect the work performed and in some cases require detailed laboratory tests and analyses. During the saturation dive evaluations, this kind of inspection was not possible, so observers relied on their own CCTV observations of the work performed or on the divers' reports of their work achievement. Laboratory tests and analyses of the work output were not planned as part of the performance evaluation program, but would be done by NCEL personnel following return of the test apparatus to the surface.

3. Physiological Measures

Initially, project plans called for obtaining physiological measures for each diver during the performance evaluation program. These measures included partial pressure of oxygen (PO_2), EKG for heart rate, respiration rate, and core temperature, and were to be used as correlates to the time measures of performance in order to identify work tasks requiring high levels of energy output. The physiological measures would also serve as safety monitors for the divers. Unfortunately, the MK-10 physiomonitors were not available during the training and baseline studies at Point Mugu.

When the physiomonitors were used at Makai Range, technical and coordination problems limited the data that could be made available. As a result of these problems, only the heart rate data were recorded for correlation with the time measures of performance.

4. Diver Debriefing Reports

Each diver participating in the salvage tool work program was required to take part in a post-dive debriefing, in order to obtain a firsthand report of his experiences and to identify any problems encountered in performing the required work tasks. Diver debriefings of the training and baseline studies at Point Mugu were conducted by Mr. Fred Barrett of NCEL and recorded on

audio tape. These debriefings were particularly beneficial in identifying problem areas in both the work task procedures and tool requirements, and in correcting deficiencies encountered in the performance measurement protocols and techniques. As the result of these debriefings, a number of changes were incorporated into the salvage tool and performance evaluation program prior to the 200-foot saturation dive.

A diver debriefing following the 200-foot saturation dive was also recorded on audio tape. The contents of this debriefing were used to provide first-hand information regarding additional problems encountered in performing the salvage tool tasks under saturated conditions.

C. Measurement Techniques

The nature of saturation diving operations clearly precluded direct observations of the salvage tasks by scientific personnel connected with the performance measurement program. Direct observations could have been employed during the shallow-water training and baseline tests at Point Mugu. However, it was decided to rely on the measurement techniques that would be employed during the saturation dives, in order to provide both training and practice for the scientific observers in their data recording techniques and communication protocols with the divers, along with diver training in the observers' reporting requirements.

The basic measurement techniques employed during the salvage task evaluations relied on the use of underwater CCTV monitoring and voice communications between the divers and a surface observer. During individual diver tasks, a hand-held video camera was operated by the diving partner and focused on the work task. For tasks such as load handling, where both divers were required to perform the task, a standby or safety diver manned the video camera. Provisions were also made to use the camera on a fixed tripod in the event that an additional diver was not available. To supplement the video information provided to the surface observer and data recorder, the divers were required to report, via their voice communications system, the status and progress of their work task. Since each diver was familiarized with the detailed salvage task analysis, they were aware of the specific task events and progress milestones which should be reported to the surface. The surface data observer was, in essence, provided with two sources of data that would enable him to record accurate, detailed, time measures of performance. In theory, the failure of either data source would not jeopardize the ability of surface observers to obtain sufficient information to record these measures, as long as the quality of the video picture or intelligible two-way voice communications were maintained.

Data forms developed prior to the training sessions were used to record the time measures of performance. The top part of the form contained background information for identification of the divers, test location, and salvage task being performed. The lower part of the form initially contained three columns for recording data. The first column, "Task Activity," provided space for noting the task elements being performed by the divers. During the training and baseline tests, this column was filled in as the divers performed the various activities associated with the task. By following the prepared task analysis, the observer was able to record the task activities in their proper sequence. Once the task activities and sequence were clearly defined, this column could be filled in prior to performance of the task. The second column provided for insertion of the

appropriate activity code description: "Task Performance (W)," "Task Preparation (P)," "Service/Maintenance (S)," or "Rest/Idle (R)." These codes could be recorded as the activities were performed, or they could be inserted following completion of the overall salvage task.

The third column was used for recording the actual time measures of performance. When the form was developed, the intent was to record activity start times from a continuously running stopwatch timer and to stop the timer only when the task was completed. Experience with this procedure showed it to work effectively only for long-duration activities such as were encountered in the load-handling tasks. An alternate method of data recording, that emerged during the training sessions as being more effective and easier for the observer to handle, was to record individual activity event times which then could be totaled to provide the total task time. This method was more effective for recording activity times of less than 1-minute duration; however, the observer had to be particularly vigilant to identify changes in the divers' activities.

In order to provide for both methods of data recording, two stopwatches were employed by the observer. One was used to record elapsed time during the task performance, while the other functioned as an individual-event timer. To accommodate this method of data recording, the data forms were subsequently modified to include two columns for time measures: "Task Time: and "Elapsed Time." The form was also modified to include additional columns for recording the heart rates of two divers. (A sample modified data form is contained in Addendum B.)

D. Personal Apparel

Every effort was made to outfit the divers in the same apparel for both the Point Mugu and Makai test conditions; however, as the result of problems in equipment availability, a number of minor modifications were made.

The basic diver apparel included hot-water-heated wetsuit, MK-10 life support system with physiomonitor and communications, five-finger gloves, and fins. However, since the MK-10 communications system was not available for the Point Mugu training and baseline dives, one member of each diving team used a surface-supplied, open-circuit air system employing a Kirby-Morgan band mask equipped with a hard-wire Helle Engineering diver communication set. This system resulted in voice communications only between one diver and the surface observer, and no communications between divers. In addition, no physiomonitors were available during the Point Mugu training and baseline dives.

E. Test Equipment and Apparatus

In addition to the tools and equipment used to perform the salvage tasks, two pieces of equipment integral to the ocean floor salvage task program were the test stand and the tool box/manifold.

The test stand was designed and built by the Naval Civil Engineering Laboratory and served to accommodate the engineering and performance evaluation testing of the tools and equipment used in the salvage tasks. The stand was approximately 8 feet square by 8 feet high, and weighed about 750 pounds. The basic framework for the test stand was fabricated from pre-punched angles and panels, such as those used to construct warehouse storage racks. The base was covered with sheet steel and had a raised lip on one side so the stand could be dragged without digging into the sandy ocean bottom. The stand provided a test plate attachment surface for installing eyebolts and padeyes, along with brackets for mounting the various types of cutting material to be used in the test. An underwater winch with its required snatch blocks were also mounted on one vertical surface of the stand. In addition to providing the primary work area for the divers, the test stand was used as one of the primary load-handling objects to be transported on the bottom, using the Aqualift variable buoyancy pontoons.

The tool box/manifold provided a receptacle for storing the salvage tools and also incorporated a manifold for distribution of hydraulic fluid to the tools contained in the box. The box was initially constructed of marine plywood reinforced with pre-punched angle iron. This construction proved inadequate for the weight of the tools and the rough handling experienced during its initial use at Point Mugu. The final version was constructed of a welded angle-iron frame covered with steel grating and partitioned into four compartments that would keep the tools separated. The manifold section of the box was fabricated of plywood reinforced with steel angle iron. The manifold panel served as a partial cover for the box, which, when placed on the ocean bottom, could be raised and bolted into a vertical position providing access to the manifold valves. The tool box/manifold was approximately 7 feet long by 3 feet deep by 4 feet high, with the manifold panel folded in its storage position. Overall weight of the unit, with tools, was approximately 350 pounds. The tool box/manifold was also used as a load-handling object for transport along the bottom, using both the hydraulic winch mounted on the test stand and the Aqualift variable buoyancy pontoons.

IV. TEST RESULTS

A. Training and Baseline Program, Point Mugu, California

The salvage task training and baseline program was conducted during a three-week period in September 1971, providing the divers with their first opportunity to perform the salvage tasks and operate the tool systems. This period also provided the first use of the performance measurement techniques developed for this evaluation program. Throughout this testing period, the salvage tools, video, and voice communications were maintained at a high level, thereby resulting in maximum training and experience for surface observers and diver personnel. Nine divers participated in the training and baseline program, performing a total of 115 salvage tool tasks during the three-week testing period. The results of the performance evaluation for these tasks are described in the following sections.

1. Load Handling -- Move test stand using large Aqualift variable buoyancy pontoon

Handling the test stand involved walking it a distance of 30 feet after it had been lifted clear of the bottom with the large Aqualift. The lifting operation involved attaching the Aqualift to the test stand bridle and inflating the Aqualift to provide sufficient lift to clear the base of the stand from the bottom. After moving the test stand to the desired position, the Aqualift was then deflated, returning the stand to the bottom. This task required two divers and was performed five times, with a total of eight divers participating. The resulting performance data are shown in Table 1.

The nature of this task required the divers to move about almost continuously. It was therefore difficult to identify rest/idle periods when, or if, they occurred. However, based on post-dive critiques, this activity category was estimated as negligible. The service/maintenance activity occurred during two repetitions of this task and involved servicing and adjusting the Aqualift lines which had become entangled. In general, the divers encountered no problems in the performance of this task, and no human engineering problems were identified.

2. Load Handling -- Move tool box/manifold using Aqualift and hydraulic winch

With the test stand in place, the hydraulic winch mounted on the stand was used to winch in the tool box/manifold 30 feet to the test stand, after the tool box was raised off the ocean bottom with the small Aqualift. This task required two divers and was performed five times, with eight divers participating. Results are shown in Table 2.

Table 1. Summary Data, Load Handling -- Move Test Stand Using Large Aqualift (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Attach safety lines to test stand (P)	1.25	9
Secure Aqualift to test stand (P)	2.09	15
Attach air line to Aqualift (P)	2.58	19
Inflate Aqualift, raise test stand (W)	1.70	13
Walk test stand 30 feet (W)	3.68	27
Deflate Aqualift (W)	0.87	7
Service/maintenance (S)	1.38	10
Total Task Mean	13.55	100

<u>Percent Allocation by Task Classification</u>:

Preparation (P) = 43%
Work (W) = 47%
Rest/Idle (R) = Negligible
Service/Maintenance (S) = 10%

Table 2. Summary Data, Load Handling -- Move Tool Box/Manifold Using Large Aqualift and Hydraulic Winch (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Unreel line from winch on test stand and attach end to tool box/ manifold (P)	3.93	15
Attach air line to small Aqualift (P)	2.82	11
Bring power handle from MAS unit to test stand (P)	2.24	8
Inflate Aqualift and raise tool box/manifold (W)	0.92	3
Attach power handle to winch (P)	2.10	8
Check MAS setting and call for power (P)	3.33	13
Winch in tool box 30 feet to test stand (W)	2.23	8
Deflate Aqualift (W)	1.52	6
Return power handle to MAS unit (S)	3.40	13
Service/maintenance (S)	3.42	13
Rest/idle (R)	0.50	2
Total Task Mean	26.41	100

Percent Allocation by Task Classification:

Preparation (P) = 55%
Work (W) = 17%
Rest/Idle (R) = 2%
Service/Maintenance (S) = 26%

Rest/idle periods were observed only on one iteration of the task. Service/maintenance times occurred on each repetition, and in each case consisted of returning the winch power handle to the MAS unit and coiling the hydraulic lines on the MAS in their storage position. This task element was time-consuming, due to the difficulty encountered in handling the stiff hydraulic lines. One minor human engineering problem was observed in attaching the power handle to the winch, in that a more positive keying device for locking the drive shaft to the winch could be developed.

3. Load Handling -- Return test stand and tool box/manifold to their original positions using the Aqualift variable buoyancy pontoons

This task required a team of two divers to return the test stand and tool box/manifold to their original positions. The task was performed in the same manner as the two previous tasks except that the hydraulic winch was not used in moving the tool box/manifold. The mean time for moving the test stand was 11.08 minutes, and the mean time for moving the tool box/manifold was 9.07 minutes. No time measures of performance were obtained for the individual task elements. No problems were encountered with this task.

4. Cutting -- Hydraulic open-center cutter cutting 1-inch wire rope and 5/8-inch steel bar stock

This was a relatively simple task for the divers and required very little preparation other than checking the manifold setting and bringing the cutter to the work area. The mean times presented, therefore, represent the actual times required for the cutter to penetrate through the material. The diver acted only to actuate power to the cutter and to keep the cutter blade in a fixed position around the wire or bar stock. Six divers participated in the evaluation of this tool. The initial cuts were made with a damaged cutter blade that was not sharp. The mean time for six cuts on 1-inch wire rope was 1.30 minutes, and the mean time for two cuts on the 5/8-inch bar stock was 2.09 minutes. When the damaged blade was replaced with a new one, ten cuts were made on the 1-inch wire rope, resulting in a mean cutting time of 0.36 minutes per cut.

No critical problems were encountered by the divers in operating this tool, other than those associated with the damaged blade. With this blade, the operator had to continually rotate the tool around the wire rope in order to penetrate all of the strands. Though it was not encountered in these tests, the 27-pound in-water weight of the open-center cutter would probably result in considerable fatigue under prolonged use by a single diver.

5. Cutting -- Abrasive saw cutting 1/2-inch by 6-inch steel plate and 1-1/2-inch-square steel bar stock

Operation of the hydraulic abrasive cutter was accomplished by an individual diver. The cutter was hand-held, using two hands to support the tool against the material to be cut. The rotary abrasive blade was actuated by a spring-loaded trigger mechanism. The rotating blade was then pressed against the area to be cut with pressure exerted by the diver until the material was penetrated. Four divers participated in this task, each making one cut in the two test items.

The mean times required to perform the task and the percent allocation to the task activities are shown in Table 3.

On two occasions the abrasive saw broke from excessive pressure against the work surface, which required the diver to change the blade. This activity was included in the service/maintenance task category.

All of the divers who performed the task were somewhat apprehensive about using this tool, since no protective guards were provided around the rotating abrasive blade, and the diver's hand could conceivably slip against the blade and result in severe personal injury. The human engineering problem was corrected by installing a protective steel guard around the blade prior to its planned use in the saturation dive.

6. Cutting -- Enerpac diver-powered hydraulic pump and cutters cutting 1-inch-diameter wire rope and 5/8-inch steel reinforcing rods

The diver-operated hydraulic pump and cutter tool required two-diver operation. One diver operated the lever-controlled hydraulic pump by lifting and lowering the pivoted lever handle to develop sufficient hydraulic pressure to close the blade of the cutter against the material to be cut. The second diver positioned the cutter unit against the work material and maintained it in position until the material had been penetrated. This task was performed by three pairs of divers, with 8 cuts made on the 5/8-inch reinforcement bar and 6 cuts made on the 1-inch-diameter wire rope. The results of this task are shown in Table 4.

The performance of this task presented no problems for the divers. While no rest/idle times were involved in the task as observed, this activity category can be expected to represent considerable time where multiple consecutive cuts are to be made.

Table 3. Summary Data, Abrasive Saw Cutting Task (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Install abrasive blade in saw (S)	1.62	14
Check manifold valve setting and ready saw at work site (P)	0.43	4
Cut 1/2-inch by 6-inch steel plate (W)	4.74	41
Cut 1-1/2-inch-square steel bar (W)	4.75	41
Total Task Mean	11.54	100

<u>Percent Allocation by Task Classification:</u>

Preparation (P)	=	4%
Work (W)	=	82%
Rest/Idle (R)	=	Negligible
Service/Maintenance (S)	=	14%

Table 4. Summary Data, Enerpac Diver-Operated Hydraulic Pump and Cutters (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
5/8-inch steel reinforcing rod:		
Insert cutter in stock (P)	0.27	32
Operate pump and cut rebar (W)	0.57	68
Total Task Mean	0.84	100
1-inch-diameter wire rope:		
Insert cutter around wire (P)	0.71	39
Operate pump and cut wire (W)	1.12	61
Total Task Mean	1.83	100

7. <u>Combination Task -- Install eyebolt using a hydraulic impact tool to drill and tap</u>

This task called for the installation of one eyebolt in a vertically mounted plate of 1-inch-thick mild steel. The task was performed by an individual diver using a 3/4-inch-drive hydraulic impact tool, hammer, and center punch. The position for the eyebolt was marked using the hammer and center punch. A pilot hole was then drilled, followed by a larger hole to accommodate the tap bit. The hole was tapped and the threaded eyebolt was screwed in and hand torqued. All drilling and tapping operation were accomplished with the hydraulic impact tool. Five divers performed the task, once each. Two additional attempts to accomplish the task were aborted, due to equipment problems. The results of the task are shown in Table 5.

From a procedural standpoint, this task presented no problems for the divers. However, minor tool problems resulted in two abortive attempts to install the eyebolt. These occurred during the tap drilling and tapping task activities. The first problem was the result of a chipped drill bit which required the diver to restart the task at a new location on the test plate. The second was a tap bit which broke off in the hole during the final phases of the tapping activity. This casualty also resulted in the task being restarted. The problem of chipping and breaking bits appeared to result from not keeping the impact tool in the same angular position in relation to the work surface.

Another minor problem which occurred during one iteration of the tapping task was that the tap would continually loosen in the chuck and have to be retightened. The total performance time for the task when this occurred was therefore approximately 2 minutes longer, as the result of this added service/maintenance time.

8. <u>Combination Task -- Install eyenut using a combination drill/tap with a hydraulic impact tool</u>

This task was very similar to the previous one; however, instead of performing the drilling and tapping tasks as separate activities, they were combined into a single task not requiring the changing of bits. Once the hole was tapped, the bit was not removed from the hole, but, instead, the chuck was loosened and removed from the exposed, threaded end of the combination drill/tap bit. The task was performed 11 times by four divers. The results are shown in Table 6. The rest/idle and service/maintenance classifications represented a negligible percent of the overall task and were not included in the tabulation.

As in the previous eyebolt task, the procedure for this task did not result in any problems for the divers. There was again the problem of breaking

Table 5. Summary Data, Eyebolt Installation Using Hydraulic Impact Tool to Drill and Tap (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Center punch (P)	0.34	4
Insert pilot drill bit (P)	0.71	9
Drill pilot hole (W)	1.12	13
Insert tap drill (P)	0.70	8
Drill tap hole (W)	1.06	13
Insert tap bit (P)	1.13	14
Tap hole (W)	1.41	17
Insert eyebolt (W)	0.77	9
Rest/idle (R)	1.04	13
Service/maintenance (S)	--	--
Total Task Mean	8.28	100

Percent Allocation by Task Classification:

Preparation (P) = 35%
Work (W) = 52%
Rest/Idle (R) = 13%
Service/Maintenance (S) = None

Table 6. Summary Data, Eyenut Installation Using Hydraulic Impact Tool with Combination Drill/Tap (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Insert pilot drill bit (P)	0.43	12
Drill pilot hole (W)	0.63	18
Remove pilot drill bit and insert combination drill/tap (P)	0.63	18
Drill and tap hole (W)	1.08	31
Remove chuck from bit (P)	0.45	13
Insert eyenut and hand torque (W)	0.31	8
Total Task Mean	3.53	100

Percent Allocation by Task Classification:

Preparation (P)	=	43%
Work (W)	=	57%
Rest/Idle (R)	=	Negligible
Service/Maintenance (S)	=	Negligible

the drill/tap bits on three occasions; however, the breaks did not occur until the taps had fully penetrated the 1-inch steel plate and the diver was removing the chuck from the bit. In removing the chuck, there was a tendency for the diver to take his holding support off the impact tool, leaving the full 10-pound weight of the tool on the exposed end of the drill/tap bit. This weight, plus the manipulations of the diver in loosening the chuck, was sufficient to break off the threaded end of the drill/tap bit.

9. Combination Task -- Install eyenut using MSA velocity power tool

The use of a velocity power tool to install an eyebolt was clearly the fastest and most efficient means of performing this task. With a loaded barrel positioned in the driver, the velocity power tool was pressed against the work surface; a slight rotation of the barrel and pressure on the barrel head against the work surface released the dual safety mechanism. Activation of the trigger mechanism at this point fired the threaded stud into the work surface. An eyenut was then screwed into the protruding, threaded end of the stud. The expended barrel was removed from the tool and replaced with a new, pre-loaded barrel, and the tool was ready to fire again. This task was performed a total of 16 times by four divers, with each diver firing 4 studs. The results are shown in Table 7.

Of the total 16 studs fired, only one misfire occurred. The safety precaution taken in this case was to try to fire the stud two additional times. If misfire continued, the barrel was carefully removed and a new barrel inserted. No human engineering problems were observed or identified in the performance of this task.

10. Combination Task -- Install 3-bolt padeye using hydraulic impact tool with individual drill and taps

Installation of the 3-bolt padeye required performance of the same task activities as were used to install an eyebolt. However, the activities were repeated three times to secure the 3 corners of the padeye plate. Bolts securing the padeye plate were torqued, using the hydraulic impact tool as an impact wrench. Threading on the eyebolt portion of the padeye was not included as part of this task. Seven divers performed the task, once each. The results are shown in Table 8.

As with the single-eyebolt task, the problems encountered consisted of chipping and breaking taps. This problem appeared to result from placing excessive pressure on the bit while tapping and from allowing lateral movement on the bit after the thread had been started. Similar problems were also experienced with some of the tap/drill bits. The observed service/maintenance time, representing 13 percent of the total task,

Table 7. Summary Data, Eyenut Installation Using MSA Velocity Power Tool (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Load barrel (P)	0.26	23
Fire stud (W)	0.17	15
Screw in eyenut (W)	0.43	38
Rest/idle (R)	0.28	25
Total Task Mean	1.14	100

<u>Percent Allocation by Task Classification:</u>

Preparation (P) = 23%
Work (W) = 53%
Rest/Idle (R) = 25%
Service/Maintenance (S) = None

Table 8. Summary Data, Three-Bolt Padeye Installation Using Hydraulic Impact Tool to Drill and Tap (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Center punch padeye position (P)	0.46	2
Insert pilot drill bit (P)	0.67	2
Drill pilot hole #1 (W)	1.16	4
Remove pilot bit and insert tap/drill bit (P)	0.88	3
Tap/drill hole #1 (W)	1.82	6
Remove tap/drill bit and insert tap bit (P)	1.13	4
Tap #1 (W)	1.58	5
Remove tap bit and insert socket (P)	1.36	5
Position padeye (W)	1.29	4
Torque bolt #1 (W)	0.33	1
Center punch positions #2 and #3 (W)	0.53	2
Insert pilot drill bit (P)	1.21	4
Drill pilot hole #2 (W)	1.55	5
Drill pilot hole #3 (W)	1.88	6
Remove pilot bit and insert tap/drill bit (P)	0.82	3
Tap/drill #2 (W)	1.82	6
Tap/drill #3 (W)	1.58	5
Remove tap/drill and insert tap bit (P)	1.16	4
Tap #2 (W)	1.51	5
Tap #3 (W)	1.05	3
Remove tap bit and insert socket (P)	0.78	3
Insert bolts #2 and #3 and torque (W)	0.82	3
Rest/idle (R)	0.78	3
Service/maintenance (S)	3.91	13
Total Task Mean	30.08	100

Percent Allocation by Task Classification:

Preparation (P)	=	29%
Work (W)	=	55%
Rest/Idle (R)	=	3%
Service/Maintenance (S)	=	13%

resulted from the time involved in the removal and replacement of the chipped and broken drill and tap bits.

11. Combination Task -- Install 3-bolt padeye using MSA velocity power tool

The 3-bolt padeye used in this task was similar to that installed by the drill-and-tap method. To install the padeye using the velocity power tool, a threaded stud was first fired into the mounting surface. The padeye plate was positioned over the exposed, threaded end of the stud, and a nut was threaded on to keep the padeye plate in a fixed position against the mounting surface. The second 2 studs were then fired through the padeye plate and into the mounting surface, and 2 nuts were threaded on the studs and torqued. Padeyes were installed by five divers using this technique. The results are shown in Table 9.

No problems were experienced by the divers performing this task other than two misfires. These misfires occurred on two consecutive barrel loads and therefore appeared to represent an inordinately large percent of the overall task time. The service/maintenance time required to handle a misfire was approximately 1.25 to 1.40 minutes and should be considered in evaluating performance on this task. The number of studs fired during the task using the velocity power tool was not large enough to determine the number of misfires that can be expected through extensive use of this tool.

Two salvage tasks initially planned for the ocean floor program were cancelled. These were the load cell task and a load-handling task which involved using a Danforth anchor in dragging the test stand.

The load cell task was found not to be a useful salvage task and was potentially dangerous to a diver's safety under saturation diving conditions. The task required strenuous physical exertion to determine the hydraulic pressure a diver could build up during a fixed time period by pumping the diver-powered Enerpac hydraulic pump against a fixed air pressure in an accumulator.

In dragging the test stand using a Danforth anchor, the available anchor did not hold in the sandy bottom, and, since it would be difficult to estimate an anchor size and configuration that would hold at the 200-foot and 520-foot work sites, the decision was made to eliminate this experiment from the ocean floor program.

A third task, the drill press task, involving the drilling of 1-1/2-inch-diameter holes in 1-inch mild steel, was designated as conditional. Training on this task was to be carried out in shallow water at Makai, using a battery-pack power source to verify the safety of the electromagnetic circuitry.

Table 9. Summary Data, Three-Bolt Padeye Installation Using MSA Velocity Power Tool (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time
Load barrel (P)	0.25	3
Fire stud #1 (W)	0.33	4
Remove barrel and reload (P)	0.62	7
Position padeye and screw in nut (W)	0.87	10
Fire stud #2 (W)	0.25	3
Reload barrel (P)	0.79	9
Fire stud #3 (W)	0.20	3
Screw on nuts #2 and #3 (W)	0.93	11
Torque nuts (W)	0.73	9
Rest/idle (R)	0.80	10
Service/maintenance (S)	2.60	31
Total Task Mean	8.38	100

<u>Percent Allocation by Task Classification:</u>

Preparation (P) = 19%
Work (W) = 40%
Rest/Idle (R) = 10%
Service/Maintenance (S) = 31%

B. Training and Baseline Program, Makai Range, Hawaii

Prior to the 200-foot saturation dive, additional salvage tool performance data were obtained in the shallow waters off the Makai Range pier. These additional baseline tests were run in order to:

1. Determine the Aqualift lifting capabilities on the heavier modified test stand and tool box/manifold.

2. Determine if the energy output requirement of the divers was excessive while operating the Enerpac diver-operated hydraulic pump.

3. Test-operate the hydraulic drill press, which had not been operated successfully during the training period at Point Mugu.

The baseline performance data recorded in the shallow-water environment off the Makai Range pier were extremely limited and, due to logistic problems with the underwater TV camera and monitoring system, were obtained only through voice communications between the divers and surface observer. The intelligibility of voice communications was excellent. However, an electrical power failure toward the end of these tests completely cut off communications, thus resulting in a break in collection of the performance data. These tests were run with the use of the MK-10 physiomonitors, and heart rate data were obtained in addition to the time measures of performance.

Two divers participated in these training and baseline tests, performing five salvage tasks one time each. The results of the performance evaluation of these tasks are described in the following sections.

1. Load Handling -- Move test stand using large Aqualift variable buoyancy pontoon

Handling of the test stand in this task required moving it a distance of approximately 20 feet, after it had been lifted clear of the bottom with the large Aqualift. The task procedure differed somewhat from that used during the training program at Point Mugu in that, in this test, the Aqualift was brought to the test stand from the surface by a diver and the actual distance the test stand was moved was only 20 feet. In addition, the task activities recorded did not include deflation of the Aqualift and lowering of the test stand following movement. The task was performed only once by two divers. The results are shown in Table 10.

The lack of visual communications with the divers precluded observation of any rest/idle activity. However, based on the content of the voice communications, it can be estimated that very little time was allocated

Table 10. Summary Data, Load Handling -- Move Test Stand Using Large Aqualift (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate	
			A	B
Bring Aqualift from surface to test stand (P)	1.50	22	121	91
Attach Aqualift to test stand and inflate (W)	1.92	27	118	94
Check Aqualift pressure (S)	1.00	14	108	78
Add air to Aqualift (W)	0.75	11	103	96
Lift test stand off bottom (W)	1.00	14	99	99
Walk test stand 20 feet (W)	0.83	12	97	99
Total Task Mean	7.00	100	107.7	92.8

Percent Allocation by Task Classification:

Preparation (P) = 22%
Work (W) = 64%
Rest/Idle (R) = Negligible
Service/Maintenance (S) = 14%

to this activity category. The service/maintenance activities recorded resulted from the requirement for the divers to check and report the amount of air the Aqualift needed to lift the test stand. Under actual operating conditions, these readings would not have been made and the Aqualift operator would have continued to add air until the object being lifted was sufficiently buoyant to move. The heart rate data recorded were considered normal throughout the task performance period.

2. Load Handling -- Move tool box/manifold using small Aqualift variable buoyancy pontoon

Handling of the tool box/manifold was carried out in the same manner as for the test stand. The task was performed using only the small Aqualift. As in the previous task, only one pair of divers performed this task. The results are shown in Table 11.

The only problem encountered by the divers resulted from the poor visibility in the area where the tool box/manifold was positioned. This caused some difficulty for the divers in locating the tool box. While this problem was not a critical one, it did represent a relatively large percent of the total task. The heart rate data recorded were considered normal, and for no task activity did either of the divers indicate any strenuous physical exertion.

3. Cutting -- Enerpac diver-powered hydraulic pump and cutters cutting 1-inch steel bar stock and 5/8-inch steel reinforcing rod

This task was performed in an identical manner to that used during the Point Mugu training tests. One diver operated the lever-controlled hydraulic pump, while the second diver positioned the cutter unit against the work material and maintained it in position until the material had been penetrated. Only one cut was made on each of the materials, with the pair of divers switching positions in operating the hydraulic hand pump. The results are shown in Table 12.

No problems were experienced by the divers in performing this task, and the heart rate data indicated that the pumping action required to operate the Enerpac had no adverse effect that would endanger the divers during the 200-foot saturation dive.

4. Drill Press -- Drill 1-1/2-inch-diameter hole in 1-inch steel plate

The drill press task was scheduled for testing in shallow water to determine whether the electromagnet was capable of firmly holding the tool in a fixed position on the test stand while it was being operated, or whether the tool

Table 11. Summary Data, Load Handling -- Move Tool Box/Manifold Using Small Aqualift (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate	
			A	B
Locate position of tool box (P)	0.92	11.2	95	96
Attach Aqualift to tool box (P)	1.00	12.1	125	100
Connect air hose to Aqualift (P)	0.50	6.1	123	99
Add air to Aqualift (W)	1.50	18.2	98	90
Walk tool box 20 feet (W)	1.83	22.2	104	98
Lower tool box and remove Aqualift (W)	2.50	30.2	100	94
Total Task Mean	8.25	100.0	107.5	96.2

Percent Allocation by Task Classification:

Preparation (P)	=	29.4%
Work (W)	=	70.6%
Rest/Idle (R)	=	Negligible
Service/Maintenance (S)	=	None

Table 12. Summary Data, Cutting Using Enerpac Diver-Operated Hydraulic Pump and Cutters (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate	
			A	B
5/8-inch steel reinforcing rod:				
Insert cutter in stock (P)	0.25	11.1	80	94
Diver A pump and cut rebar (W)	2.00	88.9	96	87
Total Task Mean	2.25	100.0	88	91
1-inch steel bar:				
Insert cutter in stock (P)	0.75	17.6	115	96
Diver B pump and cut stock (W)	3.50	82.4	91	106
Total Task Mean	4.25	100.0	103	101

was capable of drilling a 1-1/2-inch-diameter hole underwater. Also of some concern was whether the divers experienced any electrical shock while the electromagnet was activated. One diver made two attempts to perform the drilling task. The results are shown in Table 13.

A problem was experienced in operating the drill press, and performance of the task was unsuccessful. The task progressed successfully up to the point of drilling the 1-1/2-inch-diameter hole. At that time the electromagnet began to slip and the drill would not penetrate the steel plate. The task was restarted; however the same problem was encountered. While engaged in the second attempt to drill the 1-1/2-inch-diameter hole, an electrical power loss cut off communications with the divers and the task was abandoned.

Table 13. Summary Data, Drill Press Operation (Shallow-Water Baseline Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate	
			A	B
Position drill press on test stand (P)	1.00	11.0	95	98
Activate electromagnet switch (P)	0.50	5.5	100	104
Place pilot drill bit in drill (P)	0.50	5.5	89	92
Obtain power to MAS unit (P)	1.25	13.8	93	72
Idle (R)	1.08	11.9	92	89
Drill 1/2-inch pilot hole (W)	0.79	8.7	87	79
Remove pilot bit (P)	0.33	3.6	92	84
Insert 1-1/2-inch-diameter bit (P)	0.54	5.9	92	85
Drill 1-1/2-inch-diameter hole (W)	2.90	31.9	88	82
Shut off electromagnet (S)	0.20	2.2	84	61
Total Task Mean	9.09	100.0	91.2	84.6

Percent Allocation by Task Classification:

Preparation (P)	=	45.3%
Work (W)	=	40.6%
Rest/Idle (R)	=	11.9%
Service/Maintenance (S)	=	2.2%

C. Two-Hundred-Foot Saturation Dive, Makai Range, Hawaii

The operational performance data obtained during the 200-foot saturation dive suffered both in quantity and quality. While many of the problems resulted from poor weather conditions at the dive site, the salvage tool and performance measurement programs experienced additional technical and equipment problems.

Both Aqualifts were severely damaged by the heavy seas in the air-water interface encountered during the first attempt to lower the AEGIR on November 22. The Aqualifts were subsequently repaired and ready for the second attempt at the 200-foot saturation dive. To prevent recurrence of the damage sustained, the Aqualifts were lowered to the bottom on the "glug box" line after the AEGIR was submerged. This incident resulted in a one-day delay in starting the salvage tool program.

No video picture was available from the bottom for observation of the salvage tool tasks. The video camera for making these observations was a fixed camera with pan and tilt controls mounted on top of the AEGIR aft ETC. The plan was to have the divers remove this camera from its fixed mount during performance of the salvage tool tasks and use it as a hand-held camera. Unfortunately, the divers were unable to remove the camera, and it was decided to proceed with the salvage tool program without top-side observation.

During the 200-foot dive, the helium speech unscrambler used with the MK-10 communications system was not functioning properly, therefore making voice communications between the divers and surface personnel difficult to understand. This problem, in conjunction with the lack of video, severely hampered obtaining reliable salvage task performance data.

The ECG channel of the MK-10 physiomonitor did not operate properly for both divers equipped with this system. The problem was in the attachment of the electrodes on the divers in the high-humidity environment of AEGIR. When attached under these conditions, the electrodes could not be sealed properly to the surface of the skin.

The salvage tool tasks that were completed during this dive are presented in the following sections. It should be noted that, as the result of the delays in starting the 200-foot dive and the limited funds available for support of diver performance, the author was unable to be on site during this dive. All data-taking responsibility was turned over to Mr. G. L. Liffick, NCEL project engineer for the salvage tool program. Mr. Liffick was briefed on the data collection procedures and the use of the data-taking forms.

1. <u>Load Handling -- Move test stand to work site using the large Aqualift</u>

Movement of the test stand was performed from its stored position on the AEGIR deck to the designated work site off the starboard stem. The task was performed once by a single pair of divers. Results of this task are shown in Table 14.

While the procedures used in handling the test stand off the AEGIR were similar to those used in the training and baseline studies, certain modifications had to be made for the saturation dive. The primary procedure modification was to release the test stand from its secured position on the AEGIR deck. Unfortunately, the divers' activities performed in preparation for moving the test stand could not be separated into discrete task elements because of poor communications and lack of visual monitoring.

2. <u>Load Handling -- Return test stand from work site to the AEGIR deck</u>

The procedures employed for returning the test stand to the AEGIR deck departed from those originally planned, in that both the small and large Aqualifts were used. The added lifting capability was found to be necessary in order to bring the test stand to the height of the AEGIR deck. The task was performed by two divers. Unfortunately, the lack of visual monitoring and poor communications again precluded obtaining detailed time measures of the individual task activities. The performance data obtained are shown in Table 15.

Problems encountered in the performance of this task resulted from the initial addition of too much air to the Aqualifts, which caused the test stand to ascend too rapidly and become out of control. Fortunately, the end of the winch line connected to the test stand was secured to AEGIR, thereby limiting the ascent of the test stand. The test stand was brought back down to the ocean bottom with the use of the winch and hydraulic power handle. The load-handling task was then continued, using standard procedures developed for this task.

All of the tool tasks planned for this dive were performed with the test stand located on the AEGIR deck, in order to restrict the movement of test equipment and tools, and thereby saved on the limited time that remained to carry out the salvage tool ocean floor program.

On completion of the scheduled salvage tool program, the test stand was shifted with the use of the Aqualifts, in order to bring it to its tie-down position. The test stand and associated tools and equipment were secured to AEGIR in preparation for return to the surface. These additional

Table 14. Test Data, Load Handling -- Move Test Stand to Work Site Using Large Aqualift (200-foot Saturation Dive Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Range and Mean Heart Rate	
			A	B
Remove tie-down and chafing gear from test stand (P)			NO DATA	
Secure large Aqualift to test stand bridle (P)				
Attach safety line to test stand (P)	13.0	46		
Inflate Aqualift and lift test stand off AEGIR (W)	11.0	39		(106-132) 118.2
Walk test stand to work site (W)	2.5	9		(134-148) 138.7
Set test stand on bottom (W)	1.5	6		(138-148) 143.0
Total Task Mean	28.0	100		133.3

Percent Allocation by Task Classification:

Preparation (P)	= 46%
Work (W)	= 54%
Rest/Idle (R)	= Not Observed
Service/Maintenance (S)	= No Data

Table 15. Test Data, Load Handling -- Return Test Stand from Work Site to AEGIR Using Aqualifts (200-foot Saturation Dive Condition).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Range and Mean Heart Rate	
			A	B
Secure small Aqualift to test stand bridle and connect air line (P)			NO DATA	
Inflate small and large Aqualifts (overinflation resulted in test stand lifting too fast) (W)				
Winch down test stand with hydraulic winch (S)				
Walk test stand from work site to AEGIR (W)	4.0	17		(124-142) 129.5
Add air to Aqualifts and raise test stand to AEGIR deck level (W)	16.5	70		(110-152) 128.8
Position test stand over AEGIR deck close to tool box (W)	3.0	13		(120-130) 126.0
Total Task Mean	23.5	100		128.1

load-handling tasks required 35 minutes to complete. The heart rate of the monitored diver during this time ranged from 112 to 156 beats per minute, with a mean of 124.8.

3. Combination Task -- Install eyebolt in 1-inch mild steel using hydraulic impact tool to drill and tap

Two eyebolts were installed, using the same drill-and-tap method employed during the training and baseline studies. Two divers each installed one eyebolt. The data from this test are shown in Table 16.

No problems were experienced by the divers in performing this task; however, before starting the task, a third diver in band mask was sent out to get the tools from the ETC where they had been stored. This required 22 minutes to accomplish. Heart rate data shown in Table 16 are for Diver B only. The first column of heart rate data represents those obtained while Diver B was performing the eyebolt installation task; the second column shows Diver B's heart rate while observing Diver A perform the task.

4. Cutting -- Abrasive saw cutting 1-1/2-inch-square steel bar and 1/2-inch by 6-inch steel plate

Two cuts on each of the materials were made, with each diver first cutting the 1-1/2-inch steel bar, followed by the 1/2-inch by 6-inch steel plate. Since the abrasive saw was brought down without the blade installed, this task element was included in the overall task profile. When the first diver completed the cutting task, a new blade was installed by the second diver prior to his starting the cutting task. The combined results for both divers performing this task are shown in Table 17.

Table 16. Installation of Eyebolt in 1-inch Mild Steel Using Hydraulic Impact Tool to Drill and Tap (Test Data, 200-foot Dive).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate	
			Diver B Performing Task	Diver B Performing Task
Insert pilot drill bit and drill pilot hole (P, W)	3.00	25	(124-128) 126.0	(116-128) 121.5
Remove pilot drill bit, insert tap drill, and drill tap hole (P, W)	1.88	16	(120-124) 122.0	(112-116) 114.0
Remove tap drill, insert and lubricate tap, and tap hole (P, W)	6.38	53	(114-132) 123.2	(106-120) 113.5
Insert eyebolt and torque (W)	0.75	6	--- 114.0	(122-124) 123.0
Total Task Mean	12.01	100	121.3	118.0

Table 17. Abrasive Saw Cutting 1-1/2-inch-square Steel Bar and 1/2-inch by 6-inch Steel Plate (Test Data, 200-foot Dive).

Task Activity	Mean Task Time (minutes)	Percent of Total Task Time	Heart Rate: Diver B Performing Task	Heart Rate: Diver B Performing Task
Install abrasive blade in saw (S)	3.25	13	(102-116) 109.0	(118-120) 119.0
Check manifold valve setting and ready saw at work site (P)	3.00	12	No Data	(110-128) 119.3
Cut 1/2-inch by 6-inch steel plate (W)	13.75	53	(108-118) 113.5	(94-118) 103.3
Cut 1-1/2-inch-square steel bar (W)	5.75	22	(100-114) 108.0	(106-128) 116.0
Total Task Mean	25.75	100	110.17	114.40

Percent Allocation by Task Classification:

Preparation (P) = 12%
Work (W) = 75%
Rest/Idle (R) = Not Observed
Service/Maintenance (S) = 13%

V. DISCUSSION AND RECOMMENDATIONS

A. General

One of the primary stated goals of this research program was to obtain quantitative performance data of diver capabilities in performing simulated salvage tasks under the operational conditions of a deep saturation dive, and to compare such data with those obtained under relatively ideal shallow-water conditions. Based on further evaluation of these data, recommendations would be made for improved utilization and design of underwater salvage tools.

These goals were only achieved to a limited extent as the result of the delays and other problems experienced during the 200-foot saturation dive and the cancellation of the 520-foot dive, during which the major portion of the salvage tool program was to be accomplished.

Conduct of a field test program in underwater human factors research requires extensive planning along with the complete cooperation of all members of the project team. In planning the underwater work activities of the divers, in terms of task complexity and the number of tasks to be carried out, there is always the tendency to over-commit the diver's time. The rationale for this is that it is better to have too much for the diver to do than not enough. The fallacy of this philosophy comes in deciding what tasks or projects are to be eliminated when the diver's time is over-committed. Once the diving team is saturated and on the bottom, an independent action group is created, separated by x feet of water and connected only by a communications link which much of the time produces only garbled and unintelligible sounds. Therefore, when the divers are over-committed, the decision as to what tasks are to be eliminated is made by the diver team and not by the scientific or engineering personnel who are responsible for their respective programs. This problem can best be resolved by realistic scheduling of the divers' time in carrying out their assigned work projects.

In scheduling the time required to perform the salvage tool ocean floor program, the actual performance data obtained during the training and baseline studies at Point Mugu served as the basis for scheduling the divers' time. While there were no real criteria on which to estimate the salvage tool task schedule, the performance time differences between the shallow-water baseline times and those anticipated during the deep saturation dives were estimated by increasing the times by a factor of two. Since only a limited number of the planned salvage tasks were performed during the 200-foot saturation dive, there was little opportunity to determine exactly how well the time schedule would have worked.

Another factor which compounds the scheduling problems is the inevitable contingency situations which arise in a deep-ocean diving project. A case in point was the problem of the damaged Aqualifts which resulted in a full day's delay in the ocean floor program schedule. Another case was the problem encountered in removing the pan and tilt video camera from its base on the ETC, which not only was time-consuming but also severely restricted the performance observation capability. Clearly, the contingency situations which arise cannot be anticipated in terms of either time or content. However, the overall program schedule must allow for these events.

Cooperation among all members of an open-ocean diving program of this complexity and scope is essential to its success. Such cooperation can best be obtained through a complete understanding of the goals, requirements, and backgrounds of the individual scientific projects involved. Early in the program, during the baseline studies and training period at Point Mugu, the principal investigators of the various scientific projects on site at that time gave a presentation to the diving team, describing their projects and responsibilities within the overall program. These presentations did much to clear the air of any misunderstandings or questions on the parts of the divers and the scientific and engineering personnel. The use of such presentations as a means of indoctrinating personnel in the various projects and providing an opportunity for the exchange of ideas and discussion of mutual problems is highly recommended. While such presentations are time-consuming, their benefits in terms of resolving problems and misunderstandings are more than worth the effort.

B. Salvage Task Performance

Comparison of the divers' capabilities in performing the salvage tool tasks under shallow-water and deep-ocean saturation conditions were limited to the few tasks performed during the 200-foot saturation dive. These included test stand load-handling, abrasive saw cutting, and eyebolt installation.

1. Load Handling

Overall performance times for the test stand load-handling task performed under two shallow-water baseline conditions and the one 200-foot saturation dive condition are shown in Table 18. Generally, the load-handling performance times indicated that this task took about twice as long for the saturation dive. Since the divers performing these tasks during the saturation dive were extremely well trained in the load-handling procedures, the performance time differences are attributed in part to the additional stresses of the saturation environment, handling and procedural differences in operating the Aqualifts, and the divers' unfamiliarity with the area around the AEGIR.

The percent allocation of overall performance times to the four classifications of task activities did not differ significantly between the baseline conditions of Point Mugu and the test conditions of the 200-foot dive. This would further suggest that the increased time required to perform the test stand load-handling task during the 200-foot saturation dive can best be attributed to the stress factors of the saturation environment. The load-handling task, as it was performed in shallow water at Makai Range, differed considerably from the other two conditions in that the task was performed in extremely shallow water and the Aqualift was handed to the divers from the surface in close proximity to the test stand, thereby cutting down much of the time that would normally be required to bring the Aqualift to the test stand. Service/maintenance time recorded during both of the baseline conditions was attributed to checks made by the divers to determine the exact amount of air that would be required to lift the test stand. These checks were also made at Makai Range, since minor changes had been made to the test stand which influenced the overall weight of this equipment.

The load-handling task involving return of the test stand was also performed during the 200-foot saturation dive. However, the task observation and data recording during the 200-foot dive were not at a level of detail by the task activity classification. The comparative data therefore reflects the total task times. When this task was performed during the baseline test at Point Mugu, the mean time was 11.08 minutes, while

Table 18. Comparative Task Activity Times, Test Stand Load Handling.

Task Activity Classification	Baseline Point Mugu		Baseline Makai Range		200-foot Dive	
	Mean Time (minutes)	Percent	Mean Time (minutes)	Percent	Mean Time (minutes)	Percent
Preparation	5.92	43	1.50	22	13.00	46
Work	6.25	47	4.50	64	15.00	54
Rest/Idle	Negligible		Negligible		Not Observed	
Service/Maintenance	1.38	10	1.00	14	No Data	
Total Mean Time	13.55	100	7.00	100	28.00	100

during the 200-foot saturation dive the same task required 23.5 minutes. Neither of the load-handling tasks involving movement of the tool box/manifold were performed during the 200-foot dive.

These tasks provided for the use of the hydraulic power handle and winch in conjunction with the Aqualifts. While the winch system was not used in a scheduled salvage task, the system was operated during the emergency ascent of the test stand in order to haul the test stand down to the AEGIR deck. No performance difficulties were encountered during this unscheduled operation of the winch system.

2. Abrasive Saw Cutting

Table 19 summarizes the performance data on the operation of the hydraulic abrasive saw during the 200-foot saturation dive compared with the performance of this tool during the training and baseline tests.

The overall performance time for the 200-foot saturation dive was 123 percent greater than that obtained during the baseline tests. However, the percent allocation by activity classification did not differ significantly for the two conditions, with the exception of the preparation activities. This category increased from 4 to 12 percent for the saturation dive. The task was relatively easy from a tool-operating standpoint, with a mean heart rate of 114.40 beats per minute recorded for performance during the saturation dive. The human engineering problem involving the lack of safety guards that had generated some apprehension on the part of the divers during the baseline test had been corrected for the saturation dive which, in theory, should have increased the operational effectiveness of the abrasive saw. The great difference in performance times between the two conditions must therefore be attributed to unexplained factors affecting the saturated divers.

3. Combination Task -- Eyebolt installation in 1-inch mild steel using hydraulic impact tool and drill/tap method

Comparison of data obtained in the performance of this task can only be made in terms of overall performance times, due to the limited observation and communication capabilities available during the saturation dive. Total task times were 8.28 minutes for the baseline performance and 12.01 minutes for the saturation dive performance. These times represent an increase of approximately 4 minutes (or 1-1/2 times) in performance time for the saturation dive. Again, such an increase can only be attributed to unexplained stress factors acting on the divers during their saturation dive performance. Physiomonitors recorded a mean heart rate of 118 beats per minute during the saturation dive performance, indicating that a high level of energy output was not required in the performance of this task.

Table 19. Comparative Task Activity Times, Hydraulic Abrasive Saw Cutting.

Task Activity Classification	Baseline Point Mugu		200-foot Dive	
	Mean Time (minutes)	Percent	Mean Time (minutes)	Percent
Preparation	1.62	4	3.00	12
Work: Cut 1/2-inch by 6-inch steel plate	4.74	41	13.75	53
Work: Cut 1-1/2-inch-square steel bar	4.75	41	5.75	22
Rest/Idle	Negligible		Not Observed	
Service/Maintenance	1.62	14	3.25	13
Total Mean Time	11.54	100	25.75	100

4. Performance Time Comparisons -- Shallow-water baseline and saturation test conditions

Table 20 summarizes the performance times for those salvage tasks that were performed in both shallow water and at the 200-foot saturation dive condition. Each of these tasks showed a substantial increase in time required for the saturation test condition. The test stand load-handling tasks required minor variations in performance procedures during the shallow-water baseline condition, since the AEGIR was not used at that time. While movement of the test stand to and from the AEGIR deck may have accounted in part for the increased performance time, the major portion of the increase is attributed to the stress factors of saturation diving. Both the eyebolt installation and abrasive saw cutting tasks were performed without any changes in procedure between the shallow water and saturation dive conditions. Each of these tasks resulted in similar increases in the time required to complete the tasks under the saturation dive conditions. The average factor increase in performance for the four selected tasks was 1.97 times for the saturation dive.

5. Conclusions and Recommendations

Communications with the divers while they performed the salvage tasks during the 200-foot dive indicated no performance problems relating to these tasks other than those already discussed. The training and baseline tests also revealed no negative aspects of the tasks that might influence effective completion of the selected salvage tasks. It must therefore be concluded that the increased performance times experienced during the saturation dive must in part be due to factors involving the saturation aspects of the dive. These factors include:

a. General concern for the restrictive limitations associated with saturated diving.

b. Unfamiliarity with the AEGIR surroundings and the location of equipment related to the salvage tasks. (This may explain the increased performance times in the preparation activity category.)

c. Concern for personal safety and apprehension of the reliability of life support and personal apparel systems. This apprehension was found to result in the divers monitoring the MK-10 life support system readouts more frequently.

d. Reduced quantity and quality of diver-to-diver and diver-to-surface voice communications.

Table 20. Comparison of Selected Tasks Performed Both in Shallow Water and at 200 Feet during the Saturation Dive.

Task	Condition Mean Performance Time (min.)		Performance Time Differences (minutes)	Factor Increase in Performance Time for Saturation Dive
	Baseline Point Mugu Depth 40-50 ft.	Saturation Test Makai Range Depth 200 ft.		
Test stand load-handling from AEGIR to work site	13.55	28.00	14.45	2.07
Test stand load-handling from work site to AEGIR deck	11.08	23.50	12.42	2.12
Combination task -- eyebolt installation in 1-inch mild steel using drill and tap method	8.28	12.01	3.73	1.45
Abrasive saw cutting 1-1/2-inch-square steel bar and 1/2-inch by 6-inch steel plate	11.54	25.75	14.21	2.23

Specific recommendations as to how performance times may be reduced under saturated conditions would be difficult to make at this time. However, it is believed that increased performance effectiveness can result from more experience and exposure to saturation diving operations, and from increased familiarity with and training in underwater tool operations. The old adage, "practice makes perfect," may have been severely overlooked in the planning and conduct of many saturated diving operations.

C. Salvage Tools

Deficiencies in the salvage tools relating to their design and operation were limited. This was due in part to the extensive test and evaluation program conducted by NCEL prior to assignment of the tools to the Makai Range dives. In addition, the training and baseline tests at Point Mugu provided an excellent opportunity to identify and correct any minor problems which might influence the operation of the tools and/or the safety of the divers. This section briefly reviews each of the salvage tool systems in terms of their human engineering design and operating characteristics.

1. Open-Center Hydraulic Cutter

This tool operated well in cutting 1-inch-diameter wire rope and 5/8-inch reinforcing bars. However, a major drawback was its 27-pound in-water weight, which made it difficult to handle during prolonged use. Minor problems were experienced by some divers with the trigger control, which stuck in the "on" or "blade closed" position. This could be corrected by increased spring tension of the trigger or by redesign of the control mechanism to include a fixed "on/off" switch. It is also recommended that a safety cover be provided that can be swung over the cutting blade while the blade is in motion.

2. Enerpac Hydraulic Hand Pump and Cutter

This cutter was well accepted by the divers during the training and baseline tests. However, there were differences in diver opinion as to the best position from which to operate the Enerpac pump and the amount of lever throw that would be most effective. The general consensus was to operate the pump from a position that would require minimum movement and to provide a shorter handle requiring a shorter stroke. Minor problems were encountered with the two cutters associated with the hand pump. The wire cutter had a tendency to bend the last few wire strands being cut. This problem could be resolved by reducing the size of the opening in the cutting blade. The scissor-action bar stock cutter had a tendency to stick in the closed position, requiring the operator to hammer it against a solid surface in order to open the jaws. No ready solution to this problem was found.

This cutting system, requiring two divers, should be performed in such a manner that the divers have visual contact with each other. This is recommended so that signals between the divers could be exchanged when a cut is completed.

3. Hydraulic Impact Tool

The hydraulic impact tool has been widely used in the diving community for many years and is considered highly effective for a wide range of applications. Its use in this program to drill, tap, and torque presented few problems. The most important consideration to be followed when operating this tool is that it must be maintained in a perpendicular plane to the work surface. Movement around this plane will result in chipped or broken drill and tap bits. This problem was experienced during the training and baseline tests, resulting in increased performance times and a number of broken drill bits and taps. It has been recommended that a spirit level be mounted on the tool body to assist the operator in maintaining an accurate and steady tool position; however, such a system has not been tested and its benefits would have to be evaluated.

4. Velocity Power Tool

The MSA velocity power driver has undergone extensive evaluation during its development by the Naval Ordnance Laboratory and has been found to be a highly effective underwater tool. The experience with this tool during the training and baseline tests at Point Mugu proved to be no exception. As a method of installing eyenuts and padeyes, it was found to be highly effective and substantially faster than the hydraulic drilling and tapping method.

As with any explosive device, the problem of misfires must be considered. However, by using the proper safety precautions and handling procedures, these occurrences will not be a safety hazard. It is recommended that, when a misfire occurs, the misfired barrel be carefully removed from the gun and immediately tagged or coded in such a way as to be readily identified for future handling.

5. Hydraulic Power Handle and Winch

The pressure-compensated winch and hydraulic power handle which make up the winch system worked well in the training and baseline tests, and in the unscheduled application during the saturation dive. Mating of the power handle drive shaft to the winch reel was found to be difficult and excessively time-consuming, and a more positive method should be developed. It is also recommended that provision be made for a free-wheeling mode on the winch reel so that the line can be pulled off the reel easily without first being uncoiled.

6. Hydraulic Abrasive Saw

The abrasive saw had not undergone extensive testing by NCEL prior to its use in this program. During its initial use at Point Mugu, the saw

was found to require considerable leverage and pushing force for the abrasive blade to cut mild steel. In its initial design configuration, the tool was not provided with a blade guard around the bottom part of the abrasive blade. If the operator's hand slipped off the handle while generating pushing force, accidental contact with the bare abrasive blade could occur. This potential safety hazard was subsequently corrected by the addition of a blade guard. Further evaluation of this tool is recommended in order to look into the balance of the saw in various operating positions, the handle and operating control locations, and the addition of a second handle for more effective force application.

7. Hydraulic Drill Press

The hydraulic drill press scheduled for evaluation during this program was modified for underwater use by NCEL. Its general design configuration is similar to most standard drill presses, as is its method of operation. The 80-pound in-water weight of the tool clearly places it out of the hand tool category. The drill press must be placed in its working position with the assistance of a second diver or supplementary lifting device. Once in position, operation of the tool only requires the diver to control the downward movement of the drill bit.

The operating difficulties in using the drill press underwater result from problems associated with keeping the tool in a fixed, rigid position while drilling. A battery-operated electromagnetic base to keep the tool in a fixed position was developed by NCEL; however, during tests of this device in shallow water at Makai Range, the electromagnetic base would not hold against the rotary force and resistance of the 1-1/2-inch drill. While the solution to this problem is an engineering one, further redesign and modification of this tool should consider carefully the potential dangers of electrical shock associated with the electromagnetic devices.

8. Aqualift Variable Buoyancy Pontoons

The Aqualift variable buoyancy pontoons were used extensively during the load handling tasks conducted at Point Mugu. During these tests of the Aqualifts, no problems were encountered by the divers. Unfortunately, little consideration had been given to the severe strain these devices must undergo during their transit to the ocean floor. The damage sustained to the rigid fiberglass Aqualifts by the wave action of the air-water interface during submergence of the AEGIR clearly indicates the need for a major redesign of this type of lifting device. It is recommended that these devices be constructed of a flexible material so that they can be folded or compressed into a relatively flat unit providing minimum surface exposure.

D. Performance Measurement System

In developing the performance measurement system for the salvage task evaluation, primary consideration was given to its ability to provide for unforeseen problems and to deal with contingency situations. The extent to which this goal was achieved and the ability of the system to obtain and record the required performance data were for the most part successful.

The experience gained in the use of the measurement techniques developed for this performance evaluation program was extremely beneficial in terms of learning how to deal with the many problems and contingency situations which arise in an operational diving program of this nature. With this experience has also come a number of ideas as to how to conduct a performance measurement program in a field environment and how to improve field measurement techniques.

1. Organization and Program Planning

Planning and organization of the performance tests are some of the most critical phases in a diving program of this scope. The level of detail that can be specified at this time as to what tasks are to be performed, how they will be performed, and under what conditions they are to be performed will, to a large extent, determine the amount of success that can be expected in obtaining relevant performance data.

A complete understanding of the work tasks that the divers are expected to perform is essential. Personnel assigned to observe the performance of these work tasks must have detailed knowledge of them. While not always possible, it is highly desirable that the observers be qualified divers with some experience in the underwater tasks and tools being evaluated. This greatly enhances their ability to observe and communicate with the divers.

In describing and specifying the work tasks, the preparation of a detailed task analysis was found to be invaluable. This was achieved by an iterative process. The first task descriptions were very general in nature and were prepared based only on a general understanding of the salvage tool program. These were then amplified through detailed discussions with the NCEL project personnel responsible for the salvage tool program. The resulting task activity analysis was used as the basis for the task procedures employed during the training and baseline tests at Point Mugu. The final iteration of the task activity analysis evolved during the training and baseline test period as the result of the divers' experiences in performing the tasks and recommendations by the NCEL Project Engineer and the Ocean Floor Program and Training Manager. Subsequent minor modifications were made to accommodate the AEGIR operating environment.

2. Performance Observation

The use of the underwater TV system to observe the divers' performance, in conjunction with voice communications between the working divers and the topside observer, worked exceptionally well during the training period at Point Mugu. During individual diver tasks, the observing diving partner held the camera in the proper viewing position and, for teamwork tasks such as load handling, a third standby diver was assigned this function. The hand-held TV camera employed could have been improved by providing hand grips for holding the camera, along with some form of view-finder that would enable the camera operator to know the area covered in the camera's field of view. This problem was not critical, since voice communications enabled the topside observer to direct the movement of the camera until the desired field of view was obtained. The camera used was provided with remote topside focusing controls. This feature is highly recommended, since it eliminates one additional task with which the camera operator has to be concerned.

Voice communications between the diver and the topside observer are only effective if the working diver or his diving partner will transmit the information required by the observer. The divers, therefore, must be informed and trained with respect to exactly what information is required. It was found, when the required data was not being transmitted, that any prodding from topside served only to antagonize the divers. The problems encountered with voice communications during the saturation dive were not anticipated or provided for. Since transmission between the surface and the divers in the water was controlled by the diving watch supervisor, any communications between the performance observer and the divers had to be relayed through this third party. Since the diving watch supervisor was not necessarily aware of the requirements of the performance evaluation program, a large gap in the required data resulted. Two additional factors compounded the communications problem. The first was an apparent unwillingness on the part of the divers to transmit the data that was considered minimally satisfactory to meet the salvage tool performance measurement requirements. The reason for this can only be attributed to the added stresses placed on the divers in their saturated state.

The second factor affecting communications was the helium speech problem. Helium speech unscramblers have advanced to the point of enabling intelligible speech at depths much greater than 200 feet. However, helium speech is still a problem even under the best of equipment and environmental conditions. Many of the communication problems associated with the 200-foot dive were equipment-oriented and resulted in less than optimum output of the communication networks. While surface personnel can, in part, adapt to helium speech, given time, this period was not

afforded the performance evaluation observers because of the short duration of this particular saturation dive. The combination of periodic communications network failures and lack of adequate adaptation training resulted in considerable loss of the voice-transmitted data.

The problems associated with performance observation during a deep saturation dive cannot be entirely resolved but only minimized. The following recommendations are made:

a. A close working relationship and coordination among surface command personnel, scientific investigators, and diving teams is most important. In order to establish and effect this coordination, all surface watch personnel with command authority should be thoroughly versed in all ocean floor programs at a level where they understand in detail what the divers in the water are trying to accomplish, and what the goals and requirements for observation and data collection by the surface scientific investigators are. Since the diving watch officer and supervisor act as middlemen between the scientific investigators and the divers, this understanding and co-operation are essential to accomplish the goals of an ocean floor program. In turn, it is equally important for scientific personnel and divers to become thoroughly familiar with the command procedures and practices established for the given operation.

b. Divers required to provide voice data to surface personnel should be thoroughly trained and briefed regarding the information requirements of surface observers. It is believed that only through training and understanding of requirements of the surface scientific observers can the communications lag which appears to occur in a saturation environment be resolved.

c. Underwater TV cameras should be lightweight and capable of being operated by a diver during prolonged excursions. Comfortable handgrips should be provided. Where such cameras are required to cover a broad range of viewing distances, remote surface focusing capability is desirable. The provision for a diver view-finder should be incorporated in cameras under conditions where voice communications between surface observers and the diver camera operator may be restricted.

d. Where the use of hand-held TV cameras is not appropriate because of the divers' work loads, fixed cameras should be located at work sites. Such cameras should be equipped with remote-operated pan, tilt, and zoom controls. This equipment can provide maximum flexibility for surface scientific personnel and, in

many cases, can provide an observational capability equal to a diver-held camera.

e. Time line photography can also provide an excellent record of underwater performance and would give scientific investigators the capability of detailed post-dive data analysis. Such a photographic technique could be incorporated into a video tape recorder with maximum control of recording by scientific investigators while underwater work is in progress on the bottom.

f. Physiological monitoring techniques should be improved to provide greater reliability in both obtaining and recording these data. The techniques for placement and application of electrodes must be refined to provide greater stability in the water-tight integrity of the electrode seals. In the display and recording of physiological parameters, the data should not only be displayed in real time as a safety monitor for surface watch personnel, but also be recorded on a known time line. In this way, the physiological parameters of interest to the performance-monitoring personnel can be correlated accurately with the performance activity and work output data.

ADDENDUM A

DETAILED ACTIVITY ANALYSIS OF SCHEDULED SALVAGE TASKS

A. <u>Load Handling -- Move Test Stand Using Large Aqualift Variable Buoyancy Pontoon</u>

1. Remove hold-downs and chafing gear from both Aqualifts, the test stand, the tool box/manifold, and the steel plates.
2. Attach large Aqualift to test stand bridle.
3. Secure safety line to test stand.
4. Connect air line from AEGIR bottles to large Aqualift.
5. Inflate large Aqualift to raise test stand off AEGIR and lower to the ocean bottom.
6. Walk test stand 30 feet out from starboard stern quarter.
7. Deflate Aqualift and set test stand on bottom.

B. <u>Load Handling -- Move Tool Box/Manifold Using Small Aqualift and Hydraulic Winch</u>

1. Unreel rope from winch on test stand; remove air hose from large Aqualift.
2. Walk end of winch line and air hose to tool box/manifold on AEGIR.
3. Attach air hose to small Aqualift; attach end of winch line to tool box/manifold.
4. Remove power handle from MAS unit and fake out attached hydraulic hose.
5. Put MAS switch in position #2; inflate small Aqualift to raise tool box/manifold.
6. Call for electrical power to MAS unit.
7. Test-actuate power handle.
8. Insert power handle in winch and reel in rope.
9. Deflate Aqualift and lower tool box next to test stand.

C. Cutting -- Hydraulic Open-Center, Cutting 1-inch Wire Rope and 5/8-inch Steel Bar Stock

1. Position valve on MAS unit in position #1, bypass valve on manifold open.
2. Request power to MAS unit from topside.
3. Test-actuate open-center cutter.
4. Cut 1-inch-diameter wire rope.
5. Cut 5/8-inch steel bar stock.
6. Open bypass valve, close cutter valve, request "Power Off" to MAS unit.

D. Cutting -- Abrasive Saw, Cutting 1-1/2-inch-square Bar, 1/2-inch by 6-inch Steel Plate

1. Position valve on MAS unit in position #1, bypass valve on manifold open.
2. Request power to MAS unit from topside.
3. Open abrasive saw valve on manifold and close bypass valve.
4. Test-actuate saw.
5. Cut 1/2-inch by 6-inch steel plate.
6. Cut 1-1/2-inch-square steel bar stock.
7. Request "Power Off" to MAS unit.

E. Cutting -- Enerpac Diver-Powered Hydraulic Pump and Cutters, Cutting 1-inch-diameter Wire Rope and 5/8-inch Steel Reinforcing Bar

1. Wire Rope Cutter (1-inch-diameter wire rope)
   a. Attach wire rope cutter to hydraulic line from Enerpac using quick disconnect coupling.
   b. Close relief valve on Enerpac clockwise.
   c. Test-actuate cutter - Diver No. 2 pumps while Diver No. 1 watches blade come out.
   d. Diver No. 2 relieves pressure.
   e. Diver No. 1 opens guard on top of cutter, positions cutter over 1-inch wire rope and closes guard.

f. Diver No. 2 closes relief valve and starts pumping while Diver No. 1 tends the cutter.

2. Rebar Cutter (5/8-inch-diameter rebar)

   a. Connect rebar cutter to Enerpac hose.

   b. Test-actuate rebar cutter.

   c. Relieve pressure

   d. Diver No. 1 positions cutter over 5/8-inch rebar.

   e. Diver No. 2 closes relief valve on Enerpac and starts pumping. Diver No. 1 maintains cutter position.

F. <u>Combination Task -- Install Eyebolt in 1-inch Steel Plate Using Hydraulic Impact Tool to Drill and Tap</u>

1. Open bypass valve on manifold, close all others.
2. Put hydraulic valve on MAS unit in position #1.
3. Request electrical power from topside.
4. Open impact wrench valve and close bypass valve on manifold.
5. Test-actuate impact wrench.
6. Center punch eyebolt position.
7. Insert pilot drill bit in impact wrench.
8. Drill pilot hole.
9. Remove pilot drill bit and insert tap drill in wrench.
10. Tap drill hole.
11. Remove tap drill bit and insert tap in wrench.
12. Lubricate tap bit.
13. Tap hole.
14. Thread in eyebolt and hand torque.

G. <u>Combination Task -- Insert Eyenut Using a Combination Drill/ Tap with Hydraulic Impact Tool</u>

1. Insert pilot drill bit in impact wrench.
2. Center punch eyenut position.

3. Drill pilot hole.

4. Remove pilot drill bit and insert combination drill/tap.

5. Drill/tap hole.

6. Unchuck the impact wrench, leaving the combination drill/tap imbedded in the plate.

7. Screw on eyenut and hand torque.

H. <u>Combination Task -- Install Eyenut Using MSA Power Velocity Tool</u>

1. Load barrel in velocity power tool.

2. Align and position velocity power tool over steel plate.

3. Fire threaded stud into steel plate.

4. Thread eyenut and hand tighten.

5. Repeat task elements 1-4 for installation of second eyenut.

I. <u>Combination Task -- Install Three-Bolt Padeye Using Hydraulic Impact Tool with Individual Drill and Taps</u>

1. Check that valve on manifold is open and that MAS valve is in position #1.

2. Request MAS power from topside.

3. Test-actuate impact wrench.

4. Locate and align padeye on steel plate in mounting position; center punch initial hole.

5. Insert pilot drill bit in impact wrench.

6. Drill pilot hole #1.

7. Remove pilot drill bit from impact wrench and insert tap drill in impact wrench.

8. Tap drill hole #1 in steel plate.

9. Remove tap drill from impact wrench and insert tap bit.

10. Tap hole #1 in steel plate.

11. Position and align padeye on steel plate, and torque bolt #1 with ratchet wrench.

12. Make transfer punch marks in positions #2 and #3 on steel plate.

13. Remove tap from impact wrench and insert pilot drill bit.

14. Drill pilot hole #2.

15. Drill pilot hole #3.

16. Remove pilot bit from impact wrench and insert tap drill bit.

17. Tap drill hole #2.

18. Tap drill hole #3.

19. Remove tap drill bit from impact wrench and insert tap bit.

20. Run tap through hole #2.

21. Run tap through hole #3.

22. Insert washer and thread bolt onto hole #2, and torque with ratchet wrench.

23. Insert washer and thread bolt onto hole #3, and torque with ratchet wrench.

J. <u>Combination Task -- Install Three-Bolt Padeye Using MSA Velocity Power Tool</u>

1. Load barrel in stud gun.
2. Fire threaded stud into position #1 on steel plate.
3. Position padeye over the first stud and torque nut on stud using a crescent wrench.
4. Reload barrel into gun (plastic fixture on muzzle).
5. Fire threaded stud in padeye position #2.
6. Reload barrel into gun (plastic fixture on muzzle).
7. Fire threaded stud in padeye position #3.
8. Torque nuts on #2 and #3 studs.

K. <u>Drill Press</u>

1. Position valve on MAS unit in position #1, bypass valve on manifold open (all others closed).
2. Lift drill press and integral battery pack from tool box onto test plate using the small Aqualift.

3. Actuate battery switch and secure electromagnetic base to test plate.

4. Request power to MAS unit, open drill press valve on manifold, close bypass valve.

5. Test-actuate drill press.

6. Insert 1/2-inch pilot drill.

7. Drill 1/2-inch hole.

8. Remove 1/2-inch drill and insert 1-1/2-inch drill.

9. Drill 1-1/2-inch hole.

10. Remove 1-1/2-inch drill.

11. Switch off electromagnetic battery power.

ADDENDUM B

SALVAGE TASK PERFORMANCE MEASUREMENT DATA FORM

Tool Operator __________ Dive Partner __________ Observer __________

Date __________ Time __________ Location ____________________

Salvage Task Identification ______________________________

Task Activity	Activity Code	Time Measures		Heart Rate	
		Task Time	Elapsed Time	Diver A	Diver B